ECT Program
NRC Review Meeting

Advanced Energetics Project

On-Board Propulsion

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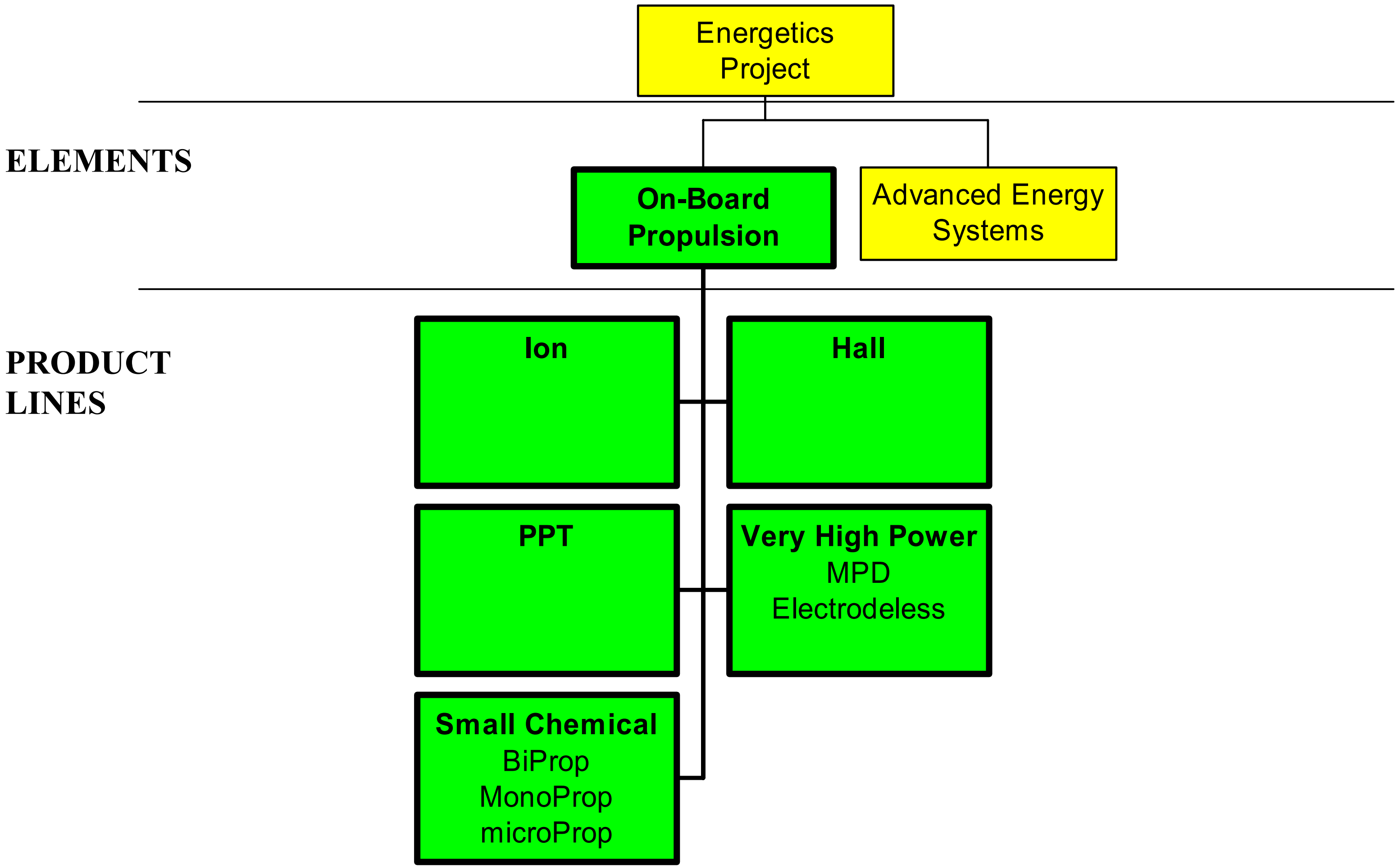
Dr. John W. Dunning, Jr.
NASA Glenn Research Center
216-433-5298
john.w.dunning@grc.nasa.gov

On-Board Propulsion
Goals and Objectives

- Develop advanced propulsion technologies to enable lower-cost, faster missions with increased capability, and to extend mission reach.
- Provide critical technology to meet the needs of ambitious agency missions
- Enable concepts such as sparse aperture satellite constellations


Energetics Project
ELEMENTS
On-Board Propulsion
Advanced Energy Systems
PRODUCT LINES
Ion
Hall
PPT
Very High Power
MPD
Electrodeless
Small Chemical
BiProp
MonoProp
microProp

On-Board Propulsion

Product Line	Product Line Managers
Electrostatic “Ion”	Mr. Michael Patterson
Electrostatic “Hall”	Mr. Robert Jankovsky
Pulsed Plasma Thrusters	Mr. Eric Pencil
Very High Power	Dr. Michael LaPointe
Small Chemical	Mr. Brian Reed Dr. Steven Schneider

On-Board Propulsion
NASA Customers

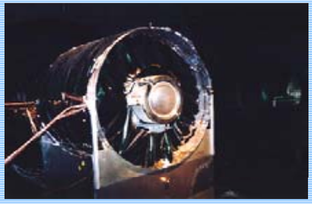
	Code S	Code Y	Code M	Code R
Electrostatic "Ion"	X		X	
Electrostatic "Hall"	X	X	X	
Pulsed Plasma	X	X		
Very High Power	X		X	
Small Chemical	X	X		X

On-Board Propulsion
FY02 Funded Tasks

Ion
Hall
PPT
Very High Power MPD Electrodeless
Small Chemical BiProp MonoProp microProp

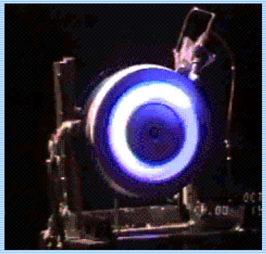
Electric Propulsion at GRC

Technologies



Ion Thruster

Magneto-Plasma Dynamic



Hall Thruster

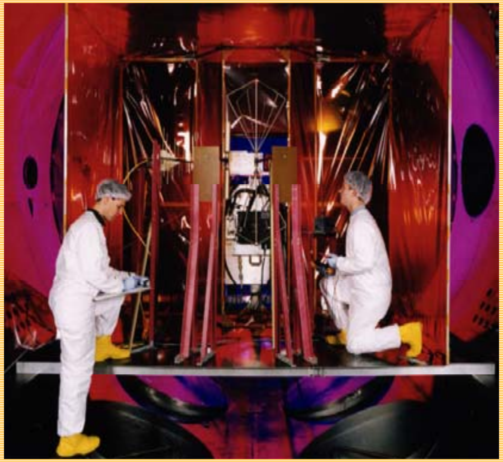
Pulsed Plasma Thruster

Facilities

Unique Development And Test Capabilities

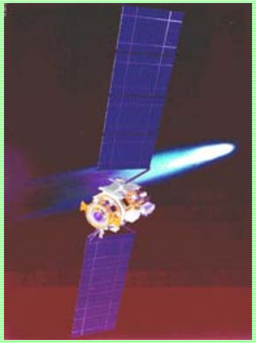
- World's highest fidelity space simulation chambers for electric propulsion (13 large, 12 small facilities)
- Extensive interactions with user community critical to technology insertion
- Strategic partnership with DOD/industry
- Unmatched technology application portfolio
- Capability from concept to flight

Personnel



Applications

NASA EO-1 with GRC PPT Engine



NASA Deep Space 1 with GRC Ion Engine

On-Board Propulsion

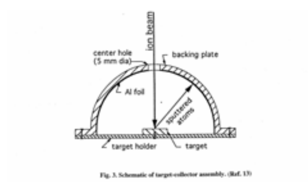
Electrostatic "Ion" Thrusters

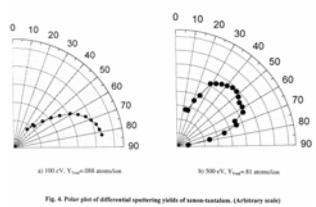
Technology Products

Gridded Ion

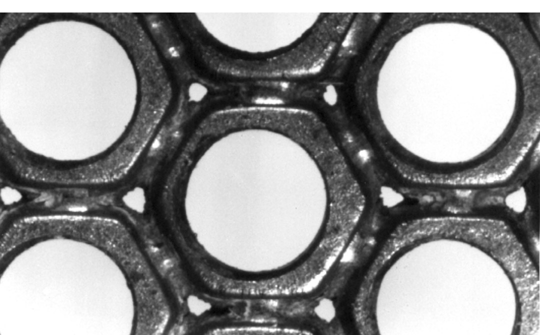
Extend NSTAR operating Range

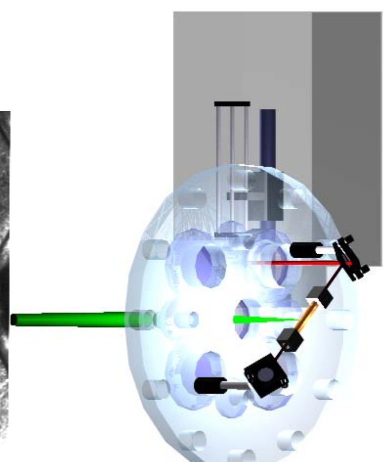
Develop 10kW, throttleable, 4000sec, 550kg engine, ~NSTAR mass





Diagnostics and Life Modeling
Component and System Level
Low Energy Sputtering
Cathode High Energy Ion Formation
Propellantless Cathode Technology
Understand wear mechanisms





Benefits

Smaller propulsion system mass fraction
More payload / science
Smaller launch vehicle

Mission Applications

Space Science*
Propulsion for all classes of missions and spacecraft sizes

HEDS
Propulsion for all classes of missions and spacecraft sizes

* Co-funding

Better understanding of EP thruster physics
More efficient engine systems
Higher power engine systems
Longer life engine systems

Ion Propulsion Roles

	Main Asteroid Belt	Trojan Asteroids	Centaur Minor Planets	Trans-Neptunian Objects	Kuiper Belt Objects / Comets

Inner Planets	Jupiter and Moons	Saturn and Moons	Uranus and Moons	Neptune and Moons	Pluto/Charon

- Solar Electric Confined to Inner Solar System
  - Also limited reach to large outer planetary bodies with aerocapture (Jupiter, Saturn, Uranus, Neptune only)

•Nuclear Electric for Large Flagship Missions to Outer Planets

–Large Targets

–Fastest (100 kW Reactor)

–>500 kg Payloads

–Delta IV Launch Vehicles

•Radioisotope Electric for New Frontiers Class Outer Solar System Missions

–Targets with low Mass

–Slower (500 W)

– <50 kg payload

–Delta II Launchers

On-Board Propulsion
Electrostatic "Ion" Thrusters

GRC Task Objectives

- Demonstrate 2x Xenon throughput improvement in a NSTAR thruster
- Perform analyses and short term tests of wear-out failure modes
- Quantify ion energy distribution in a 40 cm ion thruster discharge cathode
- Demonstrate multi-engine Xenon ion thruster operation
- Demonstrate high efficiency, light weight power processor

GRC Task Resources

	FY02	FY03	FY04
• Total Budget	$1500 K	$1500 K	$1500 K
• CS Workforce	15FTE	14FTE	14FTE
• NRA Grants			
• Other Grants	$140 K	Projected to be similar to FY02	
• NRA Contracts			
• Other Competitive Contracts	$0K	None started in FY02	
• I-H Task Support Contracts	$130K		
• CS WF Cost	$923 K		
Leverage Contributions: External to NASA	$0 K		
Leverage Contributions: Other NASA Sources	NRAs	NRAs+ Dawn	NRAs+ Dawn

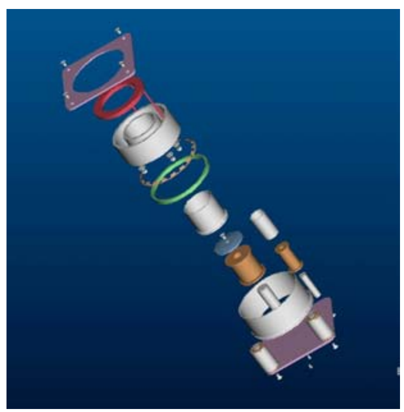
On-Board Propulsion

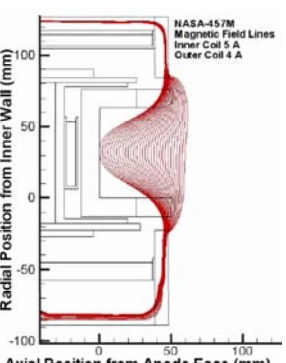
Electrostatic “Hall” Thrusters

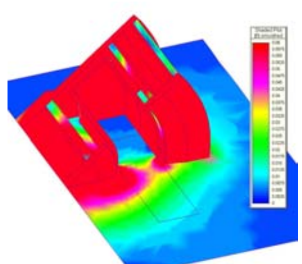
Technology Products

Hall

50kW, ~3000sec (30x SOA)
Understand physical processes & engineering constraints
Magnetic field optimization
Operation from dynamic power sources
Multiple Stage







Benefits

Smaller propulsion system mass fraction
More payload / science
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Mission Applications

Earth Science
Station keeping & Orbit maintenance
Space Science*
Propulsion for all classes of missions and spacecraft sizes
HEDS*
Propulsion for all classes of missions and spacecraft sizes
*** Co-funding**

Better understanding of EP thruster physics
More efficient engine systems
Higher power engine systems
Longer life engine systems

On-Board Propulsion
Electrostatic "Hall" Thrusters

GRC Task Objectives

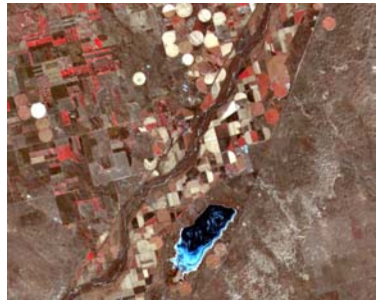
- Perform analyses and short term tests of wear-out failure modes
- Demonstrate high thrust / power concept a 50kW power level
- Understand Hall thruster erosion mechanisms as a function of design and operating conditions
- Demonstrate multi-engine operation
- Demonstrate operation from dynamic power sources

GRC Task Resources

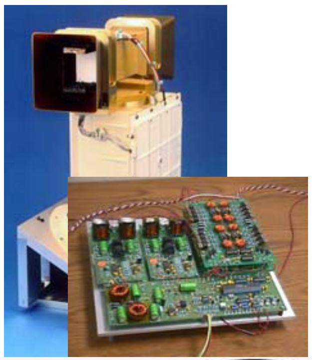
	FY02	FY03	FY04
• Total Budget	$1050 K	$1050 K	$1050 K
• CS Workforce	10FTE	12FTE	12FTE
• NRA Grants			
• Other Grants	$245 K	Projected to be similar to FY02	
• NRA Contracts		None started in FY02	
• Other Competitive Contracts	$0K		
• I-H Task Support Contracts	$234K		
• CS WF Cost	$376 K		
Leverage Contributions: External to NASA	$50 K		
Leverage Contributions: Other NASA Sources	$430K	$600K+ NRA	??+NRA

On-Board Propulsion

Pulsed Plasma Thrusters



Technology Products

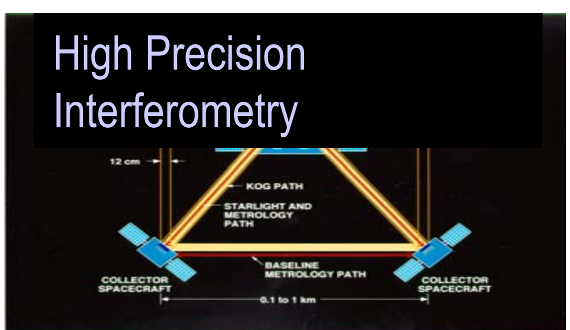


PPT

2x mass reduction
25x pulse life improvement
2x impulse bit accuracy
0.1x impulse bit

SSE - Large Space Observatories
ESE - Primary ACS
HEDS - Large Space Structure Control
100M pulse
10-1000 μN-s I_{bit}
2% I_{bit} uncertainty

Single Axis/
Single Thruster
4M pulse
Teflon
5 kg
10% efficiency
100-800 μN-s I_{bit}
750 - 1400 s I_{sp}



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Earth Science

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*** Co-funding**

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More efficient engine systems
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Longer life engine systems

On-Board Propulsion

Pulsed Plasma Thrusters

GRC Task Objectives

- Perform analyses and short term tests of wear-out failure modes
- Demonstrate high efficiency, light weight, low volume PPT and electronics

GRC Task Resources

	FY02	FY03	FY04
• Total Budget	$450 K	$450 K	$450 K
• CS Workforce	4FTE	4FTE	4FTE
• NRA Grants			
• Other Grants	$60 K	Projected to be similar to FY02	
• NRA Contracts		None started in FY02	
• Other Competitive Contracts	$21K		
• I-H Task Support Contracts	$119K		
• CS WF Cost	$217 K		
Leverage Contributions: External to NASA	$0 K		
Leverage Contributions: Other NASA Sources	$0K	$0K	$0K

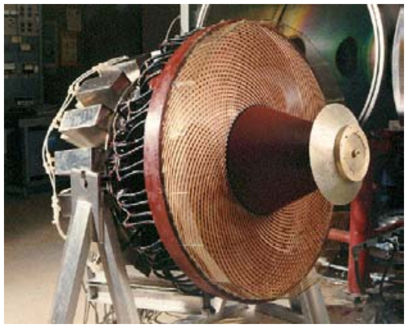
On-Board Propulsion

NRA Contracts	Resources FY02	Resources FY03	Resources FY04
<u>MIT:</u>			
• High Isp Hall Thrusters - first principle modeling of Hall thruster physics and performance	$257 K	$379 K	$125 K
<u>VAACO Industries</u>:			
• Develop a Xenon feed system using photo-chemically etched construction technology	$477 K	$400 K	$95 K
<u>JPL/GRC</u>			
• Develop advanced carbon-carbon grids to enable operation of ion thrusters at high power levels and high specific impulses	$527 K	$440 K	$515 K
<u>GSFC</u>			
• Formulate concepts, perform analysis, develop fabrication techniques, and produce and test hardware to demonstrate critical proof-of-concept functions for MEMS-based catalytic hydrogen peroxide propulsion system	$460 K	$456 K	$0 K

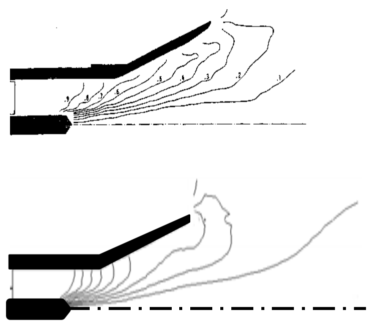
On-Board Propulsion

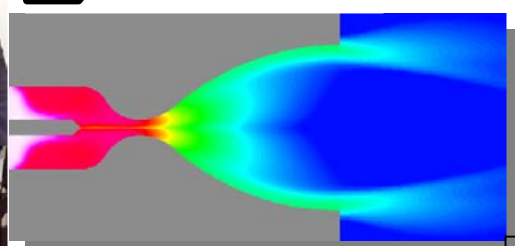
Very High Power Electric Thrusters

Technology Products



Electrodeless (PIT)
MACH2 numerical simulation
Rebuild thruster
Initiate performance evaluation





MPD
MACH2 numerical simulation
Quasi-steady state testing
0.1-5.0MW self field
0.1-5.0MW applied field

Benefits

Very short trip times
Very large payloads, >10x

Mission Applications

Space Science*
Propulsion for large, fast missions, e.g. interstellar, outer planet
HEDS*
Propulsion for fast human planetary missions
* Co-funding

Better understanding of thruster physics
Component technologies
Longer life engine systems
Model validation
More efficient engine systems

On-Board Propulsion
Very High Power Electric Thrusters

GRC Task Objectives

- Demonstrate 60% efficient pulsed gaseous MPD thruster, 0.1-1MW, 2000<Isp<7000sec
- Evaluate both self field and applied field MPD geometry
- Evaluate a variety of gaseous propellants
- Transition to steady state operation
- Complete first principle MACH2 simulation of a PIT for “long” times
- Duplicate previous PIT experiments and extend to water as a propellant
- Investigate processes in associated technologies - magnetic nozzles, plasma formation, etc

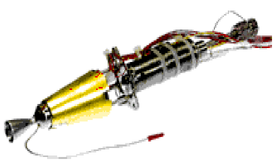
GRC Task Resources

	FY02	FY03	FY04
• Total Budget	$715 K	$700 K	$700 K
• CS Workforce	6FTE	7FTE	7FTE
• NRA Grants			
• Other Grants	$428 K		
• NRA Contracts		Projected to be similar to FY02	
• Other Competitive Contracts	$11K		
• I-H Task Support Contracts	$31K		
• CS WF Cost	$245K		
Leverage Contributions: External to NASA			
Leverage Contributions: Other NASA Sources	$100K		

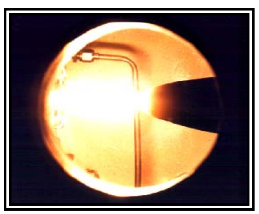
On-Board Propulsion

Small Chemical Thrusters

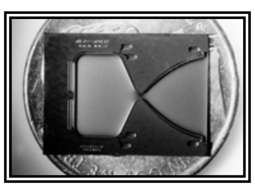
Technology Products



240-300 sec non-toxic monoprop engine system
Better understanding of non-toxic monoprop chemistry



High energy oxidizer chemistry
380 sec biprop thruster system
High performance H/O



Micro-rocket technology

Benefits

Greater Isp – enable missions
"Green" propellant – safety
Micro-propulsion for nano-craft

Mission Applications

<u>Earth Science</u>*
Station keeping & Orbit maintenance

<u>Space Science</u>
Solar system sample – return missions
Nano-craft propulsion

<u>HEDS</u>*
Attitude control / maneuvering

* Co-funding

On-Board Propulsion
Small Chemical Thrusters

GRC Task Objectives

- Demonstrate 380 sec breadboard storable rocket using hydrazine and fluorinated oxidizers with plan for life test
- Demonstrate green monopropellant formulations with a long life catalyst yielding Isp > 250 sec
- Investigate alternate non-catalytic combustion processes for green monopropellant blends
- Demonstrate non-catalytic combustion of HAN monopropellant blend
- Establish cold gas and hot gas performance of micro-nozzles
- Select chemistry for decomposing solid micro-nozzle fuel

GRC Task Resources

	FY02	FY03	FY04
• Total Budget	$840 K	$840 K	$840 K
• CS Workforce	7FTE	7FTE	7FTE
• NRA Grants		Projected to be similar to FY02	
• Other Grants	$ 50K		
• NRA Contracts			
• Other Competitive Contracts	$ 498K		
• I-H Task Support Contracts			
• CS WF Cost	$ 292K		
Leverage Contributions: External to NASA	$ 50K		
Leverage Contributions: Other NASA Sources	$ 300K	$ 300K	

Recent Accomplishments Examples

- **Successfully Completed the DS-1 ion engine mission**
- **Successfully Demonstrated a 1st Generation PPT on EO-1**
- **Won a Code S NRA for Development of a ~10kW, 4100s next generation ion engine**
- **Received Patent for "Design and Manufacturing Processes of Long-life Hollow Cathode Assemblies"**
- **Successfully Tested Pyrolytic Graphite Grids on an 8cm Ion Engine**
- **Verified Design of 50cm Grids for a 9000sec, >10kW Engine**
- **Quantified Hall Thruster Erosion/ Sputtering Mechanisms**
- **Operated GRC Designed Hall Thruster at 50% Beyond Design Point of 50kw**
- **Successfully Operated 2nd Generation PPT and Driver Electronics**
- **Operated MPD Thruster and Verified Modeling Analysis**

On-Board Propulsion
Community Connections

- Significant regular coordination/ collaboration with organizations external to GRC

  Examples:

  - Technical exchange / coordination reviews with AFRL/Edwards
    - Ad hoc splinter meeting in specific technical areas
    - Current areas of collaboration include Hall, PPT, & Monoprop
  - Integrated High Payoff Rocket Propulsion Technology (IHPRPT)
    - Coordination and regular review of propulsion technology program plans/ status
    - Sponsoring members are DOD, Air Force, Navy, Army, NASA

On-Board Propulsion
Community Connections

- Significant participation in annual conferences relevant to propulsion technology development, including:
  - Joint Propulsion Conference – 19 papers
  - International Electric Propulsion Conference – 38 papers
  - AIAA Aerospace Sciences Conference
  - Space Technology & Applications International Forum (STAIF)

On-Board Propulsion

Significant University Involvement

Arizona State University	MACH2 modeling
Colorado State University	Ion optics
Kettering University	CFD modeling
MIT	Hall "PIC" modeling
North Carolina A&T University	C/C grid materials
Ohio Aerospace Institute	High power EP
Ohio State University	Plasma thrusters
Pennsylvania State University	Mono & micro prop
Princeton University	Magnetic processes
Toledo University	Hall fundamentals
Tuskegee University	Ion sputtering
University of Illinois	PPT
University of Michigan	Ion and Hall fundamentals
University of Missouri – Columbia	Low thrust trajectory
Whitworth College	Carbon grid erosion measurements
Worchester Polytechnic Institute	PPT plumes

On-Board Propulsion
Significant Industry Involvement

APL	Lockheed
ARC	Loral
Boeing	Minteq International
Busek	Pacific NW National Lab
Ceramic Composites Inc.	Pratt Whitney
CU Aerospace	SAIC/Maxwell Labs
Fischer Engineering Co.	TRW
General Dynamics	GE/Unison
Jaycor	VAACO

Plus Many Other Suppliers of Goods and Services

On-Board Propulsion
Leverage Summary

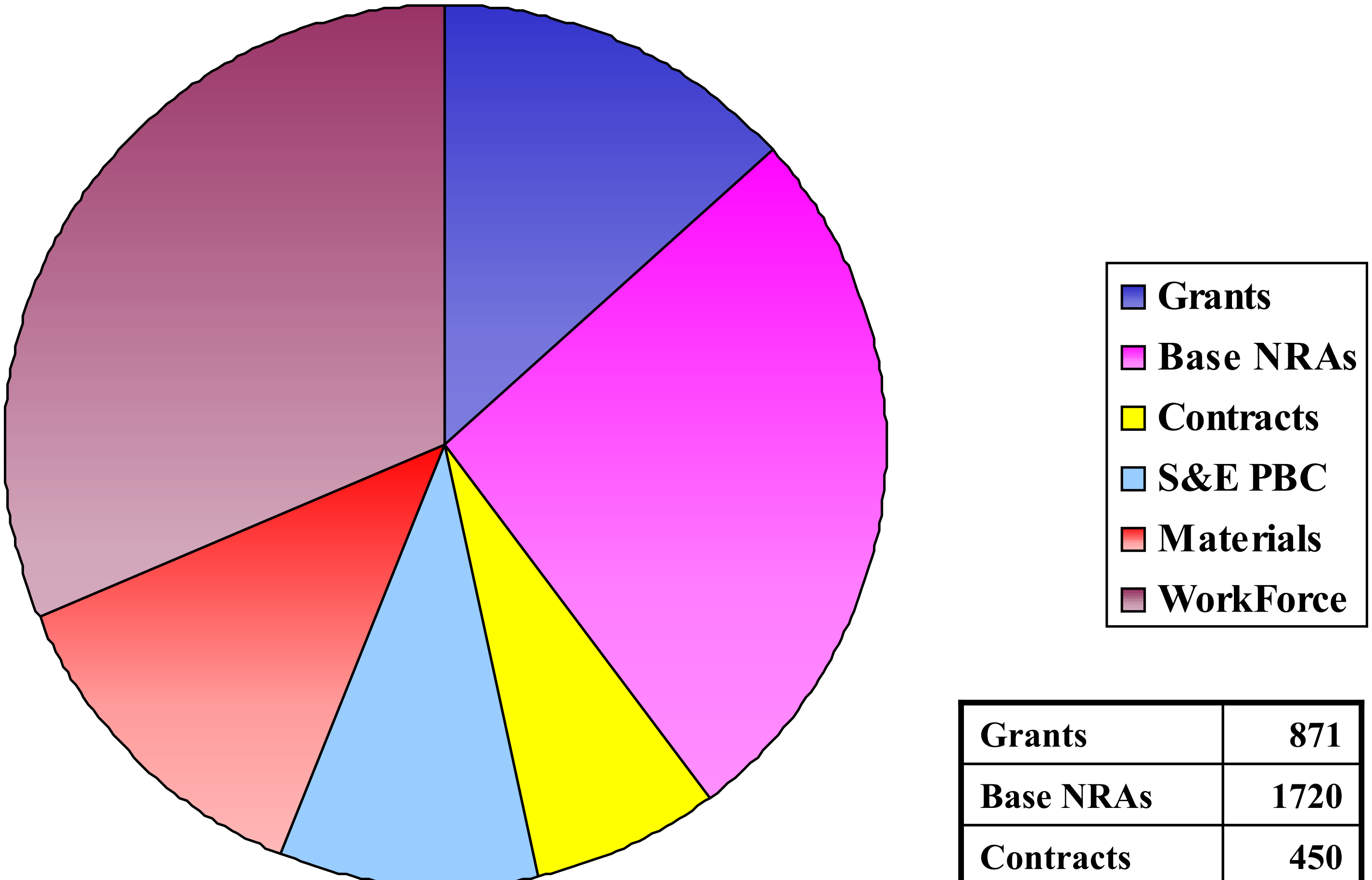
- Current Space Act Agreements include efforts with:
  - Industry organizations in area of Hall thruster development & testing
  - DARPA in area of water based orbit transfer propulsion
  - APL for EP systems related to solar system exploration
  - MDA for SBIR technical management
- Funding from other NASA sources includes:
  - Direct funding from Code S for EP system development
  - Direct funding from Code M for Hall system development
  - Funding from Code S for Next Generation Ion development
    - NRA win
    - ~10kW, 4100sec, 500kg throughput
  - Indirect funding from NASA:
    - e.g., Graduate Student Research Program (GSRP support to University researchers working at GRC)

On-Board Propulsion
Leverage Summary

- Collaboration with AFRL for Hall thruster development
- Collaboration with AFRL for Mono-Propellant development
- Co-manage IHPRPT S/C propulsion materials contracts

Advanced Energy Systems

FY02 Spending Plan

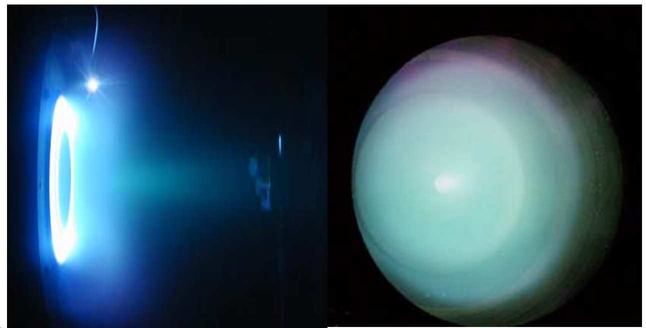


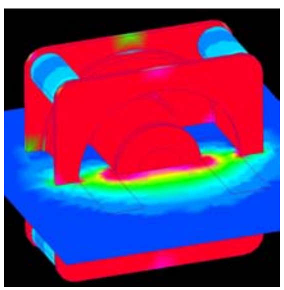
Grants	871
Base NRAs	1720
Contracts	450
S&E PBCs	629
Materials	800
Work Force	2056

Develop electric propulsion systems using mission and engineering constraints as inputs.

Physical Processes & Engineering Constraints

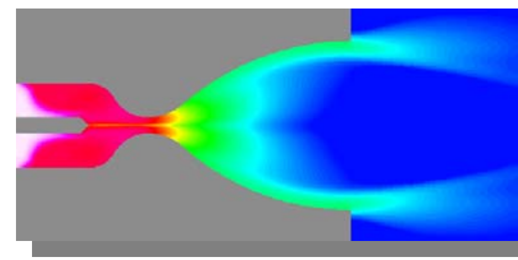
- Performance
- Magnetic System
- Thermal
- Materials
- Stability





Mission Requirements

- Isp, Thrust, Efficiency
- Throttleability
- Lifetime
- EMI
- Mass



Propulsion System

Single vs. Clusters vs. Nested

Facility Issues

- Thrust Stand
- Pumping Speed
- Chamber Size
- Power & Feed Systems
- Thermal Limitations